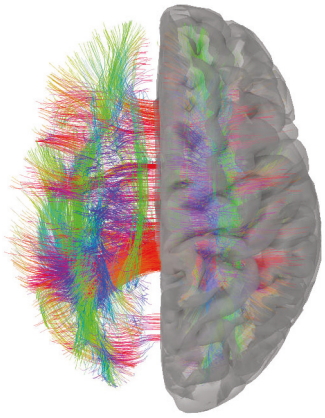
Human brain dynamics during multitasking physical navigation

Tien-Thong Nguyen DO



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UNIVERSITY OF TECHNOLOGY SYDNEY
Faculty of Engineering and Information Technology

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Thesis Submitted
in Fulfillment of the
Requirements for the Degree of

Doctor of Philosophy

Supervisors: Prof. Chin-Teng Lin
Prof. Klaus Gramann
Dr. Tim-Chen

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2020

Certificate of Original Authorship

I, Tien-Thong Nguyen Do declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Computer Science, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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ABSTRACT

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Spatial navigation is an essential skill that helps one to keep track of their location and orientation and navigate efficiently through the environment. Investigating spatial cognitive processing can be beneficial by rendering a mechanism underlying diseases such as Alzheimer's disease, which might be diagnosed based on impairments in spatial tests long before established diagnostic criteria. Furthermore, navigation in real-life often involves multiple cognitive processes, such as landmark encoding, cognitive map anchoring, and goal-oriented planning, even in the simplest situation. Thus, investigating spatial navigation under multitasking situation might provide more insight of brain dynamics underlying navigation in our daily activities.

However, most studies on active physical navigation in 3D space are based on animal research, or the studies are confined to a specific patient population with limited movement ranges. These limitations hinder the generalization of findings in stationary laboratory set-ups to active navigation in healthy human participants.

In this work, we investigated human brain dynamics while multitasking in active navigation tasks in a more natural set-up that could be used with healthy populations. We performed simulated driving and physical spatial navigation task experiments, which mimic typical navigation tasks in our daily lives. Participants performed the tasks in a virtual environment, while their brain signal was measured simultaneously. We investigated brain dynamics of concurrent multitasking in the simulated driving experiment, where participants performed the driving task, and dynamic attention shifting task concurrently. We then further investigated brain dynamics in a physical spatial navigation experiment, where participants actively

ambulated from a location to several others.

We found an increase in the information flow of brain connectivity in the period of concurrent task response in the simulated driving experiment. Furthermore, in the same experiment, we observed an increase in frontal beta during the secondary task response. We then obtained a significant modulation of theta oscillations in the retrosplenial complex (RSC) during heading changes in the physical spatial navigation experiment; this is an essential mechanism for heading computation and generating the grid cell signal. Finally, we reported that local information processing in the RSC increases linearly with the navigation load level. The findings unpack the insight of brain dynamics and offer unprecedented benefits for estimating cognitive load in active navigation.

Dissertation directed by Professor Chin-Teng Lin
Australian Artificial Intelligence Institute (AAII)
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University of Technology Sydney

To my loved ones

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List of Publications

Journal

J-1. C.-L. Lin, and **T.-T.N. Do**, "Direct-Sense Brain–Computer Interfaces and Wearable Computers". *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 51, no. 1, pp. 298-312, 2021.

J-2. **T.-T.N. Do**, Y.-K. Wang, and C.-T. Lin, "Increase in brain effective connectivity when workload increases but not with high fatigue," *IEEE Transactions on Cognitive and Developmental Systems*, 2020.

J-3. **T.-T.N. Do**, C.-H. Chuang, S.-J. Hsiao, C.-T. Lin, and Y.-K. Wang, "Neural comodulation of independent brain processes related to multitasking," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 27, no. 6, pp. 1160-1169, 2019.

J-4. **T.-T.N. Do**, C.-T. Lin, and K. Gramann, 2020, "Human retrosplenial theta and alpha modulation in active spatial navigation". **(Under review)**

J-5. **T.-T.N. Do**, T.-P. Jung, and C.-T. Lin, "Retrosplenial segregation reflects the navigation load during ambulatory movement". **(Under review)**

J-6. C. Cortes, H.-T. Chen, **T.-T.N. Do**, C.-T. Lin, "EEG Signals and Body Kinematics During Different Levels of VR Sickness". **(Under review)**

J-7. N.H.-Shariati, T. N.-John, A.K. Singh, C. Cortes, **T.-T.N. Do**, A. Craig, J.W. Middleton, M.P. Jensen, Z. Trost, C.-T. Lin, and S.M. Gustin, "Evaluation of the effectiveness of a novel brain-computer interface neuromodulative intervention to relieve neuropathic pain following spinal cord injury: protocol for a single-case experimental design with multiple baselines", *JMIR Research Protocols*, vol. 9, no. 9, pp. e20979, 2020.

Conference

C-1. **T.-T.N. Do**, A.K. Singh, C. Cortes, and C.-T. Lin, "Estimating the cognitive load in physical spatial navigation" *IEEE Symposium Series on Computational Intelligence (SSCI)*, Canberra, Australia, pp. 568-575, Dec., 2020.

C-2. **T.-T.N. Do**, C.-T. Lin, and K. Gramann, "Human brain dynamics during physical spatial navigation" *4th International Conference on Mobile Brain/Body Imaging (MoBI)*, San Diego, USA, Jun., 2020 **(Accepted)** (rescheduled to 2021 due to COVID pandemic).

C-3. **T.-T.N. Do**, and T.T. Huynh, "Evaluate effects of multiple users in collaborative Brain-Computer Interfaces: A SSVEP study" *IEEE 8th International Conference on Communications and Electronics*, Phu Quoc, Vietnam, Jan., 2021 **(Accepted)** (rescheduled to 2021 due to COVID pandemic).

C-4. **T.-T.N. Do**, C.-T. Lin, C. Cortes, A.K. Singh, J. Liu, H.-T. Chen, and K. Gramann, "Human brain dynamics during navigation with natural walking under different workload conditions in Virtual Reality (VR)" *Society for Neuroscience (SfN)*, Chicago, USA, Oct., 2019.

C-5. J. Lu, A. Wunderlich, A.K. Singh, **T.-T.N. Do**, K. Gramann, and C.-T. Lin, "Investigating the impact of landmarks on spatial learning during active navigation" *Society for Neuroscience (SfN)*, Chicago, USA, Oct., 2019.

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Abbreviation

EEG - Electroencephalography

MEG - Magnetoencephalogram

fMRI - functional Magnetic Resonance Imaging

ERSP - Event-Related Spectral Perturbation

ICA - Independent Component Analysis

AMICA - Adaptive Mixture Independent Component Analysis

PCA - Principle Component Analysis

sLORETA - standardized Low-Resolution Brain Electromagnetic Tomography

PLV - Phase Locking Value

MoBI - Mobile Brain/Body Imaging

RFP - Reference Frame Proclivity

HD - Head Direction

FMθ - Frontal Midline Theta

SAFTE - Sleep, Activity, Fatigue, and Task Effectiveness